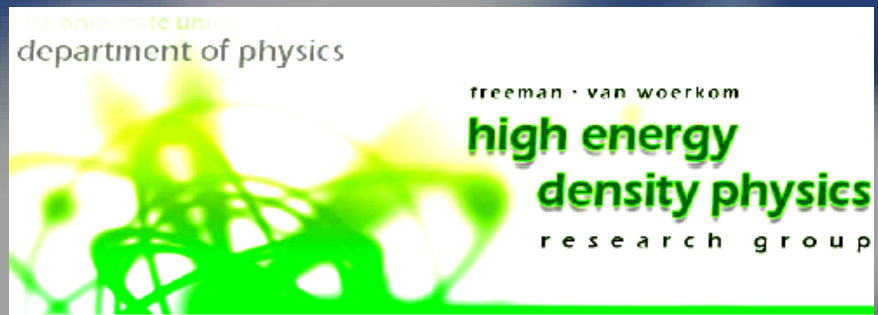
Laboratory for Advanced Laser-Target Interactions (LALTI)

For Applications in High Energy Density Science and Defense

Enam Ahmed Chowdhury
The Ohio State University

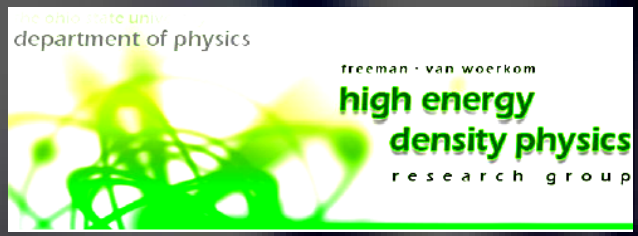


Goal

Create a facility/program for performing systematic studies on ultraintense laser-matter interactions relevant to high energy density physics in general, inertial confinement fusion in particular, national defense, and commercialization.

Science will be the primary driver for determining specifications

Collaboration



- Richard R. Freeman
- Linn Van Woerkom
- Enam Chowdhury

GENERAL ATOMICS
AND AFFILIATED COMPANIES

- Rich Stephens
- Neil Alexander
- Dan Goodin

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- Camille Bibeau
- Chris Barty
- Brent Stewart

Outline

- Motivation
- Laser-Targeting System Design (working model)
- In House Resources/Expertise
- Task breakdown
- Timeline


Motivation

Background I

- Many resources devoted to lasers over time
- Many laser-matter processes studied
- Much new technology
- Advancement slowed due to low duty cycle
- Solution = build high rep rate petawatt lasers
- Problem = what about targets?
- Example → current targets ~$1-5k
- At 10 Hertz that hurts

Background II

- Several efforts aimed at high rep-rate lasers
  - Texas, Astra/Jemini(RAL), Lucia (LULI), Polaris (IOQ/FSU Germany), MPQ, LLNL, ILE
- Few efforts in advancing targeting
  - At least not like lasers
- Shift balance of effort to integrated system
  - Use modest laser but characterize it well
  - Develop tracking
  - Develop “fast” targets

Scientific Agenda

- Collect data for large range of experimental parameters, to help benchmarking with codes
- Repeatability, Statistics!!!
- To understand absorption processes
- To understand relativistic charge transport
- To explore efficiencies
  - Laser-electron → front surface morphology
  - Laser-proton → rear surface morphology
- To develop diagnostic abilities
  - Transfer technology to large facilities


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Laser-Targeting system design (working model)

Dream Scenario

- Hertz-ish repetition rate → laser, target & diagnostics
- Multi-Petawatt peak power
- Focused $I \geq 10^{20}$ W/cm^2
- Laser stable to few percent for 8 hours
- Laser focus pointing stability within 1 (one) μm
- No prepulse → $I < 10^{11}$ W/cm^2 100 ps before main pulse
- Flat-top focus
- Handle complex targets → cones, spirals,…
- Target chamber remain under vacuum ~hours

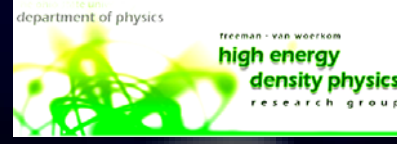
System Requirements

- 0.1 – 1.0 Petawatt Peak Power (3-30 J compressed @ 30 fs)
- Must produce peak focused intensities in the range of 10^{19} - 10^{21} Wcm^{-2}
- 10 shots/hour scaleable to Hz level
- Two short pulses → proton beam probe
- Possible addition of long pulse heating beam(s)
- Spatio-temporally well characterized laser shots
- Automated target insertion & alignment (Rich Stephens, GA)
- Maintain focal spot pointing stability within ±0.5ϕ
- Reasonable contrast ratio → ≥ 10^{7}:1
- Total cost ~ $10 million

Alignment Procedure Issues

- Diagnostics produce fixed point in space
  - How do we make it & find it?
- Feed and Align target to diagnostic center (Rich Stephens)
  - How to align rep-rated targets?
- Align laser to target (Rich Stephens)
  - straightforward using industrial technology?
- Maintain optimal focal properties
  - How do we move focus w/o destroying focus?
- Some diagnostics use collection optics
  - K_α & XUV
  - Can we move the collection optic and align to the target?
- How do we improve laser pointing stability?
  - Control environment, install appropriate dampners
  - Use minimum path length and optics

Hybrid Concept Schematic



Pockell cell
Spatial filtering

Multipass NOPA

3 mJ
10 Hz

1nJ,
200 - 500 ps

100 nm bandwidth
pulse stretcher,
combined with
pulse shaper

10-25 fs
oscillator,
800 nm

Midlevel multipass
amplifiers

2J, 10 Hz

Power Amplifier

40 J
1 shot/5 min

- Thermal loading issues
- Need to load w/o amplifying
- Feedback to adaptive optics
- Scaleable to higher PRR

Terawatt
Compressor

Probe
pulse

diagnostic

diagnostic

diagnostic

diagnostic

Petawatt
Compressor

30J/pulse
30 fs

- target must align to diagnostics
- laser must align to target

Deformable optics

Multipass NOPA

- Eliminates regen ghost pre-pulses, gain narrowing, and higher order dispersion terms
- 3-4 pass with 10 mm BBO crystal, 300 mJ 7 ns pump (e.g. Jovanovic et. al. *Opt. Lett.* **27**, 1622)
- Parametric super-fluorescence needs to be reduced
- Modeling finds a gain of 80/pass, so overall 10^6 gain is feasible.

150 J, ~532 nm High Energy Pump?

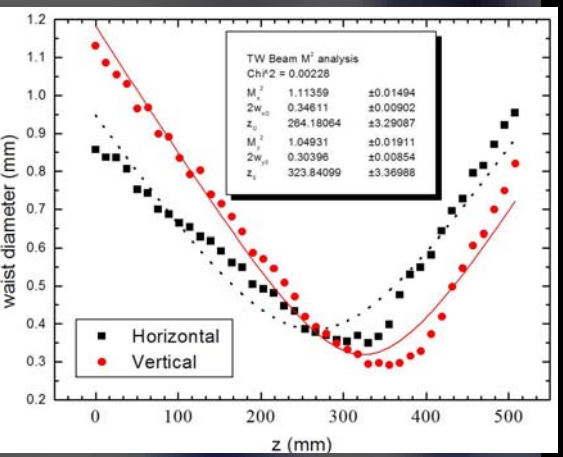
- Diode pumped
  - High repetition rate possible
  - Expensive
  - New, relatively untested technology
- Flashlamp pumped
  - Cost effective
  - Known technology
  - Low repetition rate


In House
Resources/Expertise

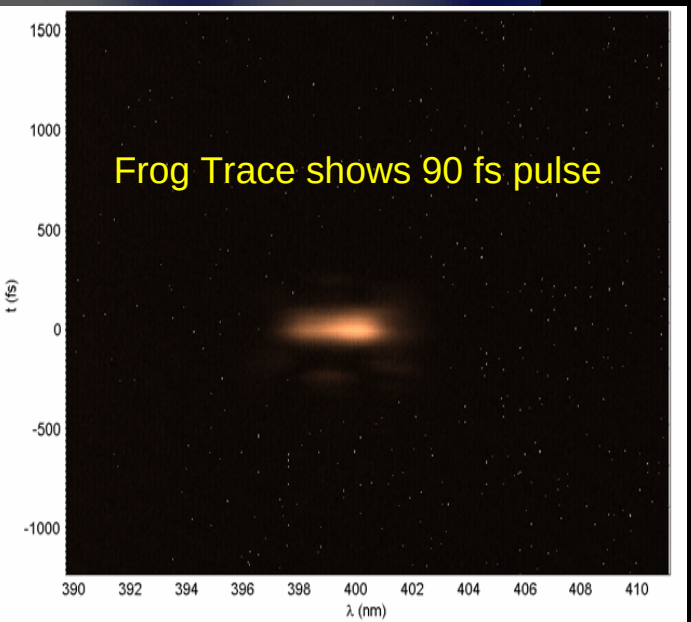
Resources

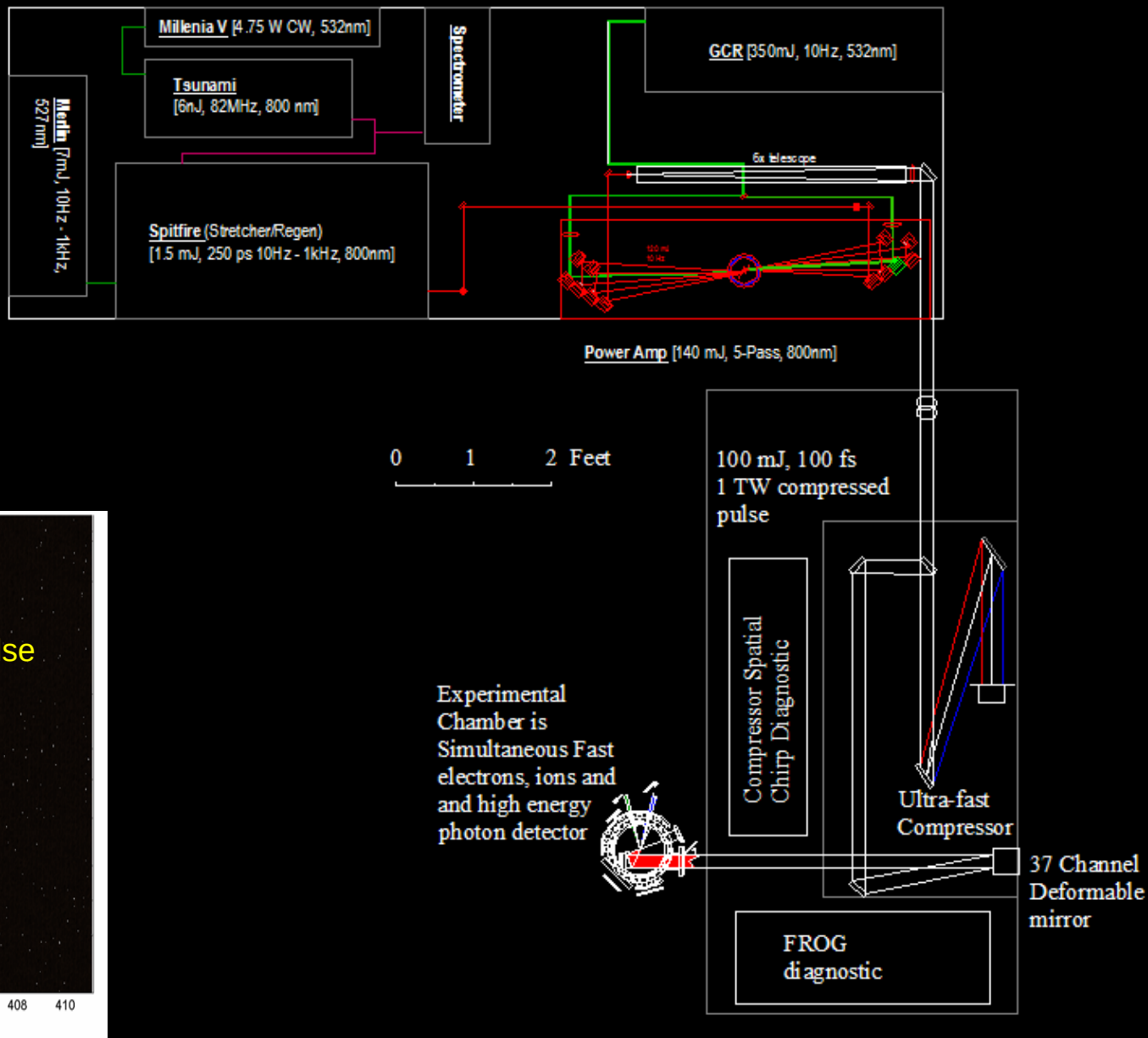
- 1 TW Ti:Sapphire laser completed in February 2006
- 4 TW OPCPA @ 2 microns to be completed in 2008
- One full building dedicated to Petawatt project with ~5000 sq. ft lab space with office space and a machine shop
- Currently 1 post doc (me) and 3 grad students involved
- Plan to hire engineers/laser scientists.

Current Laser System: 1TW

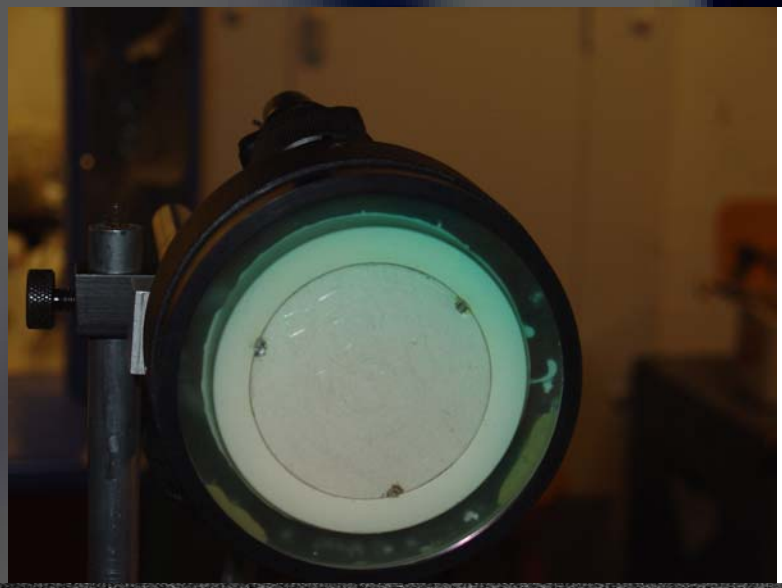


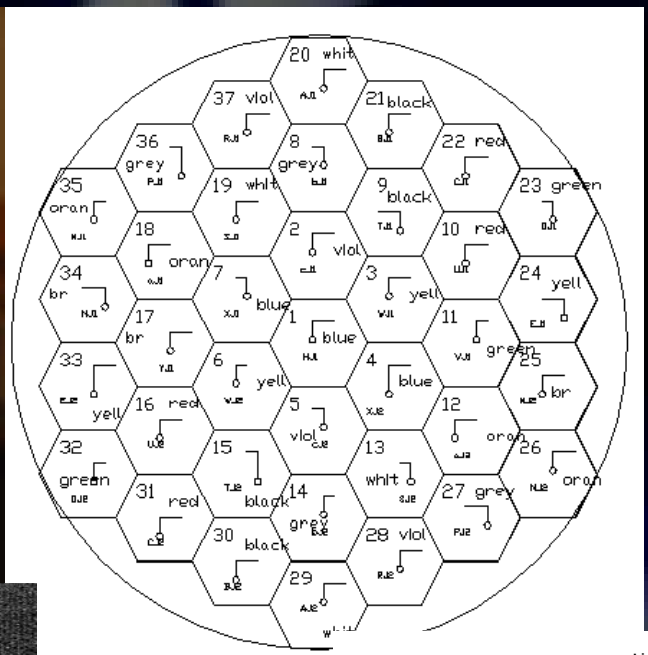
$M^2 = 1.1$



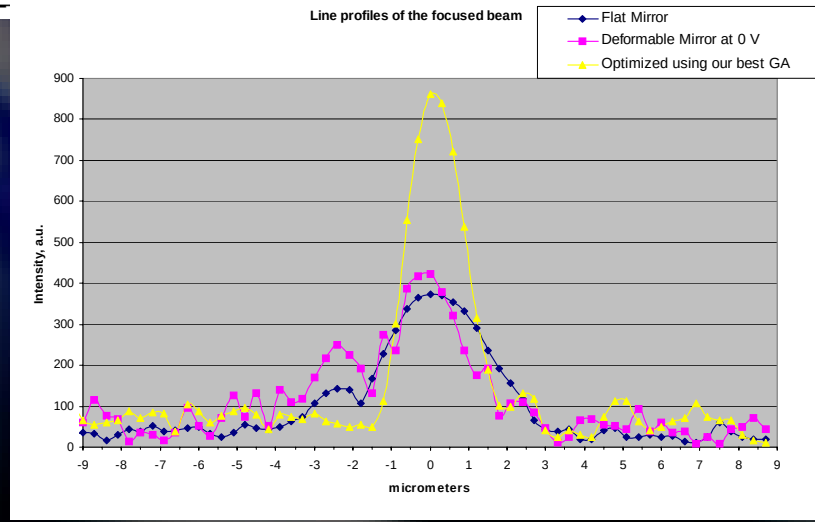


Adaptive Optics





Deformable mirror AT26/37. Segmentation layout, channel locations, wires colors and connectors addresses.



The genetic algorithm with range -60 to 60 V and step size .1 was able to increase the peak intensity of the beam by a factor of two

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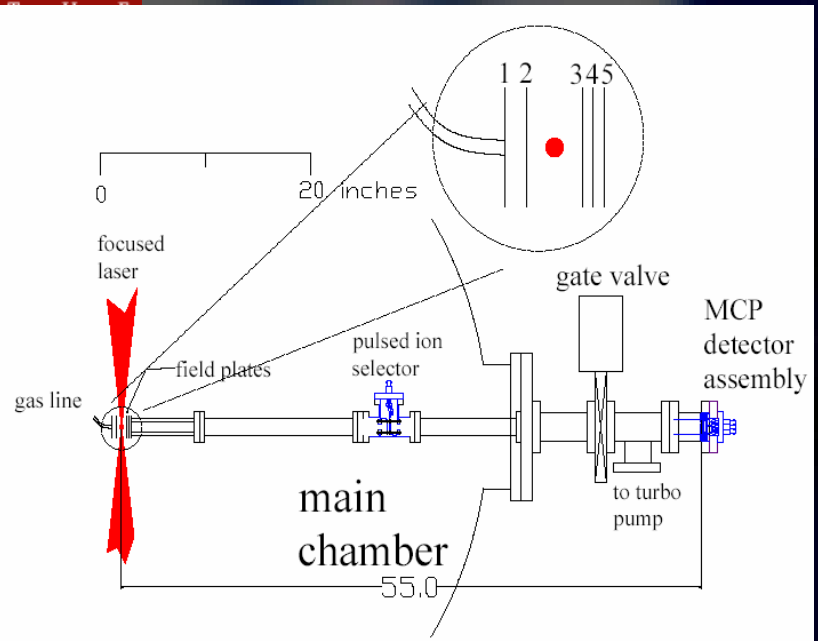
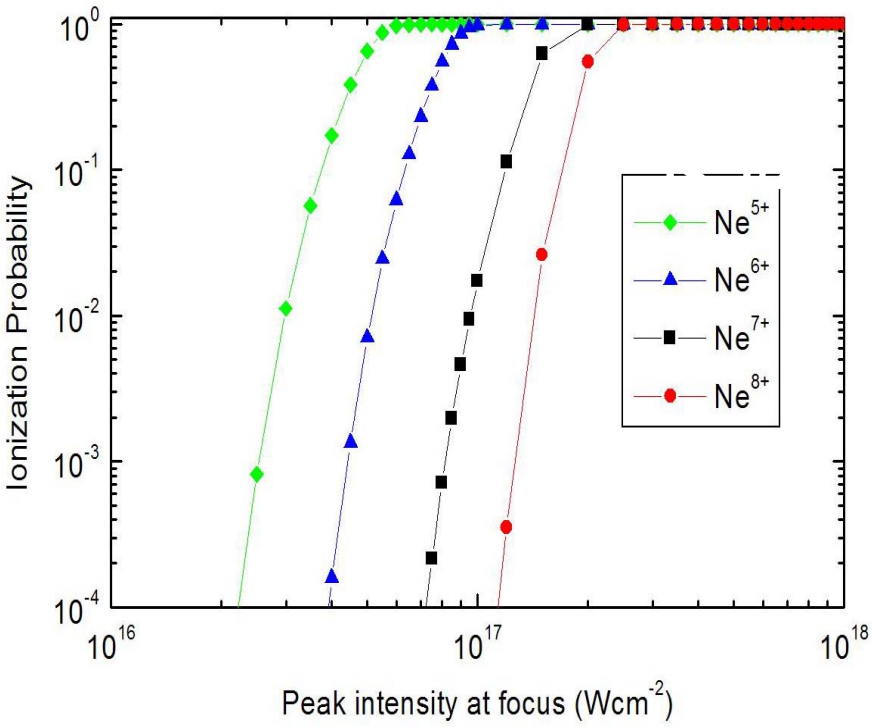
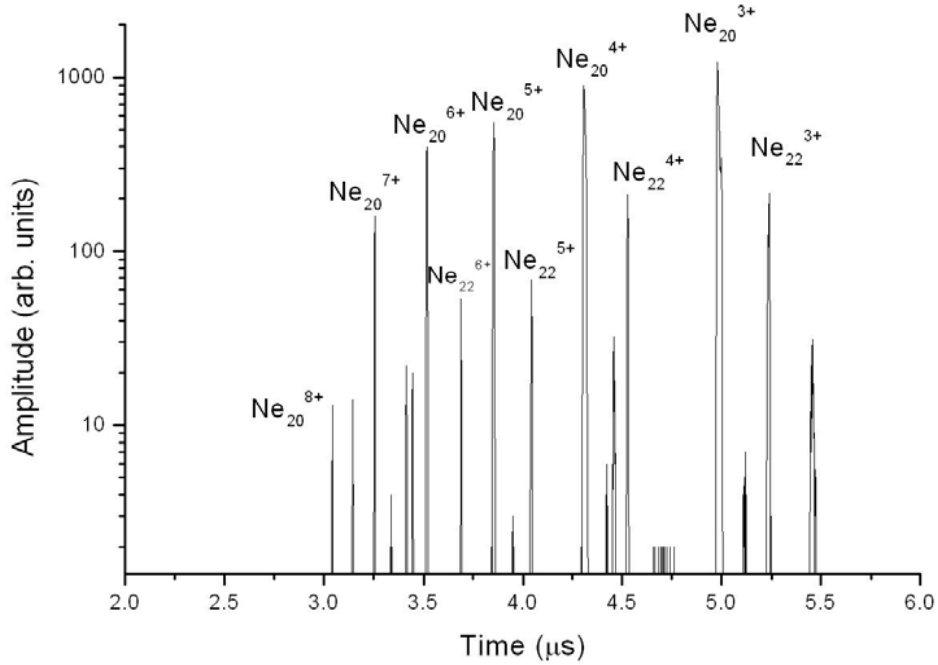
In Situ Peak Intensity Measurement







Task Breakdown

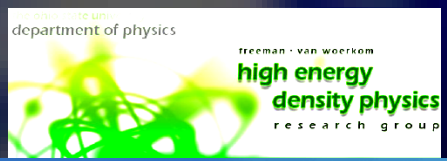
- Build prototype system at Ohio State
  - Whole facility construction cost $10-20 million
  - For FYI 2006, $2 million granted
- Develop modular technologies
  - **OSU**
    - **Laser Construction**
    - **Perform physics experiments in support of**
      - **Fundamental science**
      - **NNSA initiatives**
      - **Applications**
  - **GA**
    - **Mass production of cost effective Targets**
    - **Fast target insertion with fiducials**
  - **LLNL**
    - **Conceptual design matrix for Laser System**
    - **User facility for some concept target exp**

Rough Timeline

- First year
  - Explore targeting issues & designs
  - Determine laser architecture
  - Build laser front end (100 mJ)
  - Explore rep-rated diagnostics
- Second year
  - Build prototype targets & chambers
  - 50 TW laser complete
  - Work on laser pointing, and characterization
- Third year
  - Phase 1 integration of laser & targets & diagnostics
  - Work on power amplifiers to Petawatt
- Fourth year

Conclusion

- Create a truly unique facility/program for systematic studies in HEDP
- Concentrate innovations on targeting
- Only as much laser as we need (30J, 30 fs)
- Act as a center for training a new generation scientists in HEDP



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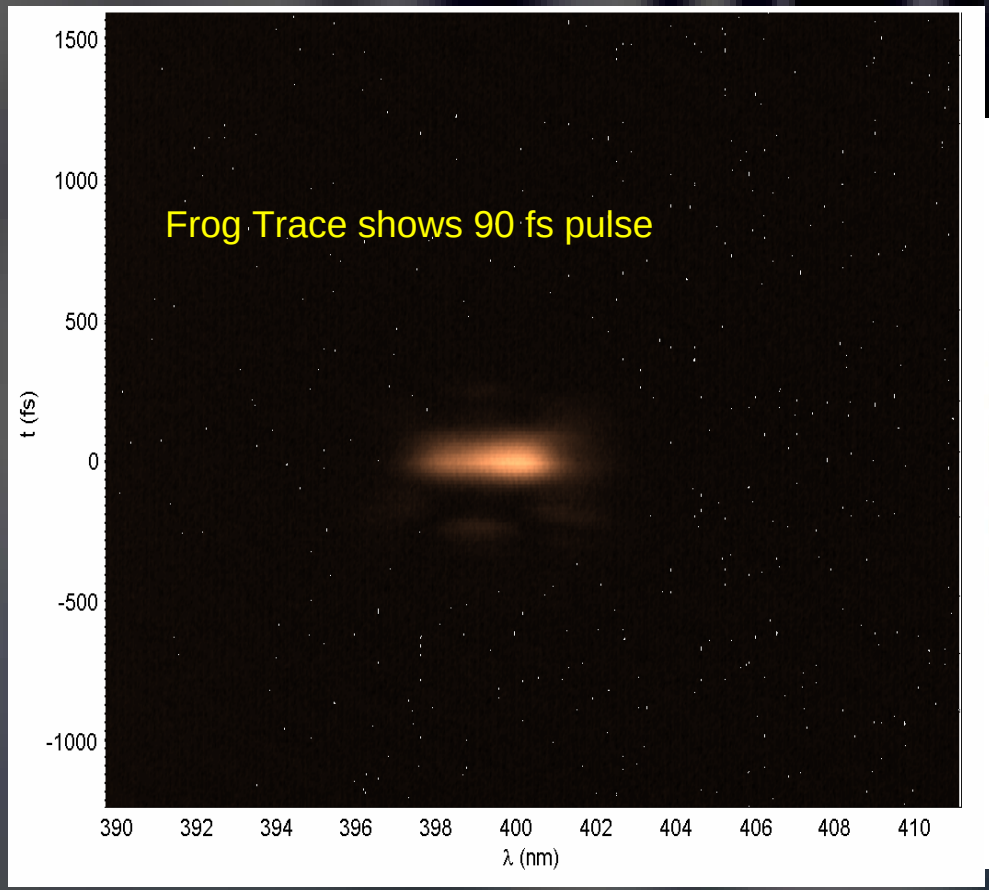
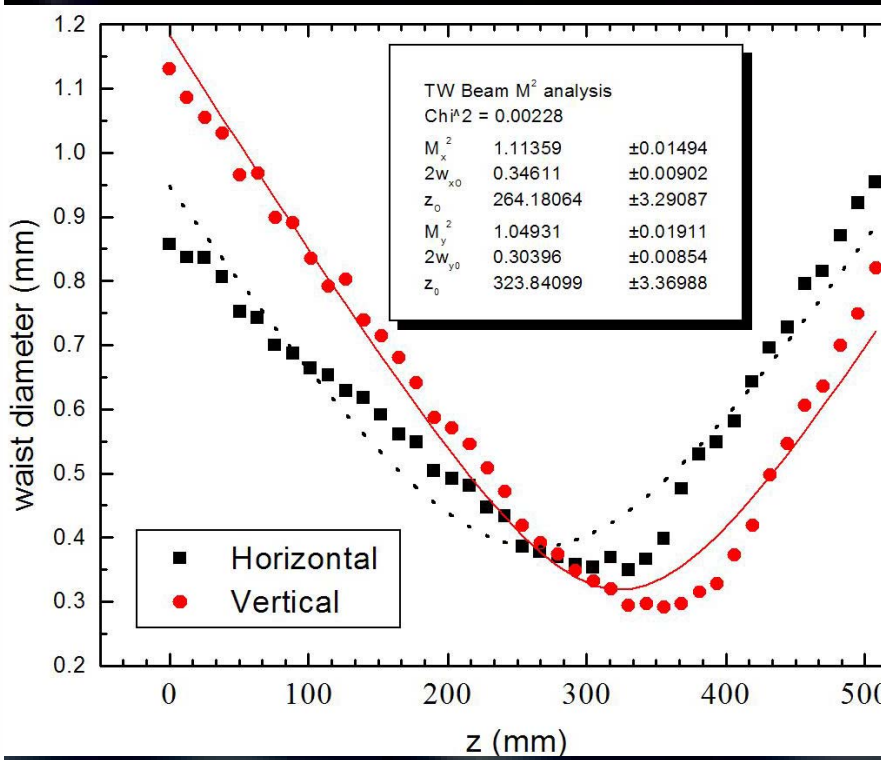

Frog Trace shows 90 fs pulse
t (fs)
λ (nm)
1500
1000
500
0
-500
-1000
390
392
394
396
398
400
402
404
406
408
410


TW Beam M² analysis
Chi^2 = 0.00228
M²x 1.11359 ±0.01494
2wx0 0.34611 ±0.00902
z0 264.18064 ±3.29087
M²y 1.04931 ±0.01911
2wy0 0.30396 ±0.00854
z0 323.84099 ±3.36988
Horizontal
Vertical
waist diameter (mm)
z (mm)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
100
200
300
400
500